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Research

POST Weed Control Using Halosulfuron in Direct-Seeded Watermelon

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Watermelon growers rotate crops to prevent problems, but weed populations in new fields may hold unexpected control challenges. Having effective POST herbicides would provide growers an opportunity to respond to emerging weeds on an as-needed basis. To address this need, field studies were conducted over 4 yr in Oklahoma to determine efficacy and crop response of POST halosulfuron applications to direct-seeded watermelon that received PRE application of ethalfluralin at 840 g/ha. At 5 wk after crop emergence (WAE) halosulfuron was applied at 18, 27, 36, and 54 g/ha. The 27 g/ha rate was also applied at 1, 2, 3 and 7 WAE. Halosulfuron applications made 5 WAE did not provide acceptable (> 80%) control of pigweeds and cutleaf groundcherry regardless of rate. Applications made 1 WAE provided significantly better control of pigweeds and cutleaf groundcherry than did later applications. Halosulfuron treatments of 36 and 54 g/ha made 5 WAE and of 27 g/ha made 1, 2 and 3 WAE did not result in significant yield increases compared with the hand-weeded check. These studies show that POST halosulfuron application may be a useful treatment for direct-seeded watermelon. This option would enable more judicious use of herbicides and possible reduction in production costs.

Nomenclature: Halosulfuron; Palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; tumble pigweed, *Amaranthus albus* L. AMAAL; cutleaf groundcherry, *Physalis angulata* L. PHYAN; eclipta, *Eclipta prostrata* L. ECLAL; watermelon, *Citrullus lanatus* (Thunb.) Matsumura & Nakai var. lanatus 'Jubilee', 'XIT 101'.

Key words: Broadleaf weed control, watermelon injury.

Weed control is needed in watermelon production to avoid losses in crop yield and marketability that result from weed interference (Monks and Shultheis 1998; Terry et al. 1997). Not only does weed control provide direct benefits to crop yields, but uncontrolled weeds hamper the management of insect and disease pests and reduce harvest efficiency. Watermelon production in central regions of the United States may occur during mid- to late summer after the typical market price decline that occurs between early and mid-summer (Lu et al. 2003a, b). Expected market prices at this time of year may not justify the expense of intensive production inputs such as plastic mulch or hoeing practices, which contribute to weed control. Therefore, other weed control options are needed. Several herbicide options are available for use at the time of planting (Boyhan et al. 1995; Mitchem et al. 1997) and combinations of herbicides have been used to broaden the spectrum of weed control in melon crops (Umeda 2002). More recently, an additional option is the PRE use of halosulfuron, which was evaluated by Brandenberger et al. (2005a) and found to be effective for controlling several broadleaf weeds in watermelon. Halosulfuron is approved for use in several cucurbit crops and the specific uses vary with crops (Anonymous 2005). This is due in part to differences in tolerance to halosulfuron among cucurbit crops (Webster et al. 2003). For watermelon, halosulfuron is approved for use with direct-seeded and transplanted crops on both bare ground and under plastic mulch (Anonymous 2005). When used under plastic mulch, halosulfuron is generally directed at nutsedge (*Cyperus* spp.) control (Webster and Culpepper 2005). Applications are made before planting or, in the case of direct seeding, immediately after seeding and before crop plants emerge. When used before planting, the registration indicates a risk of crop injury if treated soil is moved into the planting hole. Currently, POST application that allows halosulfuron to contact watermelon foliage is not approved. An effective POST application would be beneficial in that it would provide growers the option of waiting until weeds emerge before choosing to use a herbicide. This would be of particular value to growers who often plant in new land and do not have information regarding the weed species that are present in a given field.

A 2002 survey of eight southern states of the United States listed pigweed species (*Amaranthus* spp.) as one of the most common and most troublesome weeds of cucurbit crops (Webster 2002). Some *Amaranthus* species have been shown to reduce watermelon yields (Terry et al. 1997). Although eclipta and cutleaf groundcherry are also distributed through the southeast United States (SWSS 1993), there are few reports on the effect of these weeds on vegetable crops. While reported to be weeds of several crops, there is little documentation regarding interference from these two species (Bell and Oliver 1979; Hoyt et al. 1996; Porter 1993). Eclipta is reported to be an important weed of peanut (Sholar and Nickels 1999). This crop is often grown on lands used for watermelon production (Lu et al. 2003a), and watermelon growers report eclipta as an increasing problem. Bell and

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Oliver (1979) found that interference from cutleaf groundcherry had no significant effect on soybean yield in Arkansas.

Control of pigweeds, cutleaf groundcherry, and eclipta using PRE or POST applications of herbicides has been documented (Bell and Oliver 1979; Culpepper et al. 2001; Eizenberg et al. 2003; Hartzler and Foy 1983; Sholar and Nickels 1999), but little work has been reported on the use of sulfonylurea herbicides for weed control in watermelon. Halosulfuron is a systemic, sulfonylurea herbicide (Vencill 2002) developed for agronomic and vegetable crop use. The compound has both PRE and POST activity on several weed species (Talbert et al. 1998). Several cucurbits, including muskmelon (*Cucumis melo* L. *reticulatus* group), honeydew (*C. melo* L. *inodorus* group), and cucumber (*Cucumis sativus* L.), have shown tolerance to POST application of halosulfuron (Brandenberger et al. 2005b; Buker and Stall 2001; Miller and Libbey 1999). Several weeds that occur in watermelon production areas, including cutleaf groundcherry, Palmer amaranth, and tumble pigweed, are not listed as weed species controlled by halosulfuron (Anonymous 2005); therefore, evaluation of additional species is needed to determine the efficacy of halosulfuron for use in commercial watermelon production.

The purpose of these studies was to determine crop safety for watermelon and effectiveness of halosulfuron applied POST at various rates and application timings for control of annual weeds in the South-Central Plains area of the United States.

Materials and Methods

Study Site Information. Field studies were conducted on research stations at Bixby, OK in 2001 and 2002, and at Lane, OK in 2004 and 2005. Soil was a Severn very fine sandy loam (coarse-silty, mixed, calcareous, thermic Typic Udifluvents) at Bixby and a Stigler very fine sandy loam (fine, mixed, thermic Aquic Paleudalf) at Lane. In each case, soil was characterized by low organic matter (0.8% or less) with pH values of 5.9 at Bixby and 7.0 at Lane. Watermelon cultivars were 'Jubilee' at Bixby in 2001 and 'XIT 101' for 2002, 2004, and 2005 studies. Study sites were selected on the basis of the presence of known weed populations. Palmer amaranth was the primary species at Bixby, and cutleaf groundcherry, tumble pigweed, and eclipta were the predominant species at Lane. Seedling populations in nontreated plots ranged from 35 to 50 m^2 for each species.

At each site, from May to late June, as appropriate for the site and field conditions, watermelon was direct-seeded into finely prepared seedbeds that were prepared just before planting. Seeds were planted with a pneumatic planter[1] at Lane and a hand-pushed planter[2] at Bixby. Plot size was one row with 2.7 to 3.7 m between row centers and 7.6 to 10 m long. Watermelon plants were thinned to a row spacing of 0.6 to 1 m between plants 1 to 2 wk after emergence (WAE). Both sites received overhead irrigation as needed. Check plots receiving no weed control (weedy) and hand weeding (weeded) were also included. Hand weeding was initiated for weed-free check plots at 2 to 3 wk after crop emergence and was continued as long as possible without causing excessive watermelon vine disturbance.

Experimental Procedure. Halosulfuron treatments included four application rates: 18, 27, 36, and 54 g/ha applied at 5 WAE. For the 27 g/ha rate, additional application timings of 3 and 7 WAE were used at Bixby and application timings of 1, 2, 3, and 7 WAE at Lane. Ethalfluralin was applied PRE at 840 g/ha to all treatments receiving halosulfuron using CO_2-pressurized four-nozzle hand-boom sprayers[3] calibrated to deliver 187 to 281 L/ha at pressures of 124 to 221 kPa. Halosulfuron treatments were applied with the same spray equipment and parameters. Halosulfuron applications included nonionic surfactant[4] at 0.25% v/v.

Data Collected and Statistical Analysis. Crop injury was evaluated at the seedling stage as visually observed stunting and, following the seedling stage, as phytotoxicity. Phytotoxicity was a visually observable and comprehensive assessment of crop injury that included discoloration, shoot appearance, and vine stunting. Evaluation of percentage seedling stage stunting was made at 10 to 17 d after treatment for halosulfuron applications that were made 1 to 3 WAE. These evaluations were made on the watermelon crop by comparing treated plots to the weedy check, on a scale of 0 (no injury) to 100% (no seedling growth). Phytotoxicity was recorded at 4, 6, and 9 WAE on a scale of 0 (no injury) to 100% (plant death). Visual evaluations of weed control were made 6 and 8 WAE of watermelon for individual weed species using a scale of 0 as no control to 100% as complete death of weedy species. Watermelon fruit were harvested once in all studies and fruit were weighed individually so that yield data included the number and weight of marketable fruit for each plot. Fruit weighing at least 2.3 kg were considered marketable. Yield was reported as Mg/ha and fruit/ha of total marketable fruit. Each experiment of the study used a randomized complete block design with four replications. All data were analyzed using analysis of variance with PROC MIXED in PC SAS software Version 8.2.[5] A split-plot arrangement was assumed such that replications within locations were considered blocks, and time was the split factor when appropriate. For the analyses involving time, simple effects of treatment at a given time period were analyzed with a SLICE option in an LSMEANS statement. When the SLICE option was significant at a 0.05 significance level, multiple comparisons for treatment were performed using a DIFF option (i.e., protected pairwise *t* tests) at a 0.05 significance level. For analyses involving effects of halosulfuron on weed control, contrasts were used to test for linear responses to application rate.

Results and Discussion

Weed Control. Timing of POST application of halosulfuron at 27 g/ha affected control of pigweed, eclipta, and cutleaf groundcherry (Table 1). Part of this control was due to the PRE application of ethalfluralin. On the basis of evaluations made at the 6-wk rating, and before the 7 WAE halosulfuron application, ethalfluralin resulted in 53% control of pigweeds, 19% of eclipta, and 29% of cutleaf groundcherry. In all cases, best overall weed control was obtained with halosulfuron applied 1 WAE. Control of pigweed species decreased significantly when halosulfuron application was delayed to 2

Table 1. Effect of POST application timing of halosulfuron after PRE application of ethalfluralin on weed control in watermelon across locations (Bixby and Lane) and years.[a,b]

Halosulfuron application timing WAE	Visual weed control ratings[c]											
	Pigweeds				Eclipta				Cutleaf groundcherry			
	6-wk rating (4)[d]		8-wk rating (3)		6-wk rating (2)		8-wk rating (2)		6-wk rating (2)		8-wk rating (2)	
	%											
1	100 a[e]	[5][f]	100 a	[5]	98 a	[5]	99 a	[7]	85 a	[5]	88 a	[7]
2	73 b	[4]	52 c	[6]	99 a	[4]	90 a	[6]	71 a	[4]	73 a	[6]
3	86 b	[3]	79 b	[5]	99 a	[3]	99 a	[5]	44 bc	[3]	49 b	[5]
5	72 c	[1]	71 b	[3]	70 b	[1]	92 a	[3]	47 b	[1]	25 b	[3]
7	53 d	[-]	58 c	[1]	19 c	[-]	71 b	[1]	29 c	[-]	34 b	[1]

[a] Halosulfuron treatments were applied at 27 g/ha and included a nonionic surfactant at 0.25% v/v and followed a PRE application of ethalfluralin at 840 g/ha.

[b] Abbreviations: WAE, weeks after emergence of watermelon.

[c] Visual weed control ratings where 0 = no control and 100 = complete kill; a weedy check (untreated experimental unit) is used as a reference; weed control ratings were made at 6 and 8 wk after crop emergence. ''Pigweeds'' represents combined data for tumble pigweed and Palmer amaranth.

[d] Numbers in parentheses are the quantity of experiments included in the analysis.

[e] Values within a column followed by the same letter are not significantly different (P = 0.05) using protected pairwise *t* tests.

[f] Numbers in brackets that follow means are the number of weeks after halosulfuron application that the evaluation was made; [-] indicates that no treatment was applied before the evaluation date.

WAE. As with pigweed, groundcherry control declined with delayed application such that control from the 2 WAE treatment fell to an unacceptable level. Unlike pigweed and cutleaf groundcherry, eclipta was controlled 92% at 8 WAE, which was 3 wk after treatment (WAT) by applications made as late as 5 WAE. Eclipta was the only weed for which the 7 WAE application provided good control (71% at 1 WAT).

The effect of halosulfuron rate on weed control when applied at 5 WAE is presented in Table 2. For pigweed species and eclipta there were no significant linear rate responses. Pigweed control was not acceptable (72 to 77%) when evaluated at 1 WAT and 3 WAT. Eclipta, on the other hand, was controlled greater than 90% with all halosulfuron rates when evaluated at 3 WAT. For cutleaf groundcherry there was a significant linear response to halosulfuron rate at 3 WAT. However, the greatest control received (40%) was well below a meaningful level. These results indicate that POST application of halosulfuron applied at 27 g/ha should be made no later than 1 WAE to obtain weed control of the species evaluated. The 2- and 3-WAE treatments at this rate (Table 1) provided only partial control of pigweed species and cutleaf groundcherry. The reduced control with later applications is likely due to weed growth stage exceeding that suggested for control with application rates used in this study. Therefore, rates higher than those evaluated should be tested for possible improvement in controlling these weeds when applied 2 through 5 WAE.

Crop Effects. Halosulfuron injured watermelon, which included seedling-stage stunting and phytotoxicity. Seedling-

Table 2. Effect of application rate of halosulfuron applied 5 wk after watermelon emergence and following PRE application of ethalfluralin on weed control across locations (Bixby and Lane) and years.[a,b]

Treatment	Application rate (g/ha)	Visual weed control ratings[c]					
		Pigweeds		Eclipta		Cutleaf groundcherry	
		1 WAT (4)[d]	3 WAT (2)	1 WAT (3)	3 WAT (2)	1 WAT (2)	3 WAT (2)
		%					
Halosulfuron	18	72 b[e]	64 b	64 b	98 a	49 b	19
Halosulfuron	27	72 b	71 ab	70 b	92 a	47 b	25
Halosulfuron	36	77 b	70 ab	69 b	98 a	45 b	32
Halosulfuron	54	77 b	69 b	56 b	99 a	52 b	40
Weed-free check	-	99 a	82 a	99 a	66 b	88 a	80
Linear response for application rate[f]		ns	ns	ns	ns	ns	*

[a] Halosulfuron treatments were applied at 27 g/ha and included a nonionic surfactant at 0.25% v/v and followed a PRE application of ethalfluralin at 840 g/ha.

[b] Abbreviations: WAT, weeks after treatment.

[c] Visual weed control ratings where 0 = no control and 100 = complete kill; a weedy check (untreated experimental unit) is used as a reference. Pigweeds represent combined data for tumble pigweed and Palmer amaranth.

[d] Numbers in parentheses are the quantity of experiments included in the analysis.

[e] Values within a column followed by the same letter are not significantly different (P = 0.05) using protected pairwise *t* tests.

[f] Test of significance for a linear response to herbicide rate; ns, not significant; * significant at P = 0.05.

Table 3. Effect of halosulfuron application timing on crop stunting and phytotoxicity across locations (Bixby and Lane) and years.[a,b]

Halosulfuron application timing WAE	Crop injury						
	Seedling stunting[c]	Phytotoxicity (% injury)[d]					
		4-wk rating[e]		6-wk rating		9-wk rating	
	(% of untreated)	%					
1	24 a[f]	1 c	(3)[g]	1 b	(5)	1 b	(8)
2	22 a	5b c	(2)	1 b	(4)	2 b	(7)
3	19 a	12 a	(1)	1 b	(3)	3 b	(6)
5	5 b	7 b	(-)	5 b	(1)	2 b	(4)
7	2 b	1 c	(-)	9 a	(-)	21 a	(2)

[a] Halosulfuron treatments were applied at 27 g/ha and included a nonionic surfactant at 0.25% v/v and were preceded by a PRE application of ethalfluralin at 840 g/ha.

[b] Abbreviation: WAE, weeks after emergence of watermelon.

[c] Lane studies in 2004 and 2005 were evaluated 10–17 d after treatment.

[d] Phytotoxicity is a visually observable and comprehensive assessment of crop injury that includes discoloration, shoot appearance, and vine stunting, where 0 indicates no injury and 100 denotes extremely abnormal plants.

[e] Rating timing in weeks after crop emergence.

[f] Values within a column followed by the same letter are not significantly different ($P = 0.05$).

[g] Numbers in parentheses that follow means are the number of weeks after halosulfuron application that the evaluation was made; (-) indicates that no treatment was applied before the evaluation date.

stage stunting was observed after halosulfuron applications made from 1 to 3 WAE (Table 3). Although stunting was < 24%, this effect was short-lived and crop injury was no longer present when rated at 6 WAE. Halosulfuron applied 5 WAE did not stunt watermelon (data not shown). Phytotoxicity was expressed as shortened internodes at the apical region of shoots after POST applications. However, with the 5-WAE treatments, which included application rates as great as 54 g/ha, this injury was minimal and short-lived (data not shown).

Timing of halosulfuron application influenced crop phytotoxicity (Table 3). The phytotoxicity, although statistically significant, was overall minimal. For example, after the 3-WAE application, the 4-WAE (1 WAT) evaluation showed 12% injury. Two weeks later phytotoxicity was only 1% for this treatment. Phytotoxicity was pronounced after the 7-WAE application when it averaged 21% injury, and was primarily evident as stunting of shoot terminals.

Crop Production. Yield in terms of fruit weight and number was affected by halosulfuron treatment (Table 4). Among the greatest fruit weights were those of watermelon that received the earliest halosulfuron application timings and the weed-free check (Table 4). For watermelon treated with halosulfuron at 3 WAE, fruit weights were significantly greater than those of the 5- (for the 27 g/ha rate) and 7-WAE applications by 46 and 33%, respectively. Fruit quantities (no./ha) were also affected by application timing. There were more marketable watermelon fruits in plots receiving the 1- and 3-WAE treatments than in the 5-WAE treatment (at 27 g/ha). However, no differences in fruit number were detected between the weed-free check treatment and any other halosulfuron application timing at the 27 g/ha rate.

Fruit weight (Mg/ha), but not fruit number, was affected by halosulfuron rates when applied 5 WAE. Among the 5-WAE treatments, the greatest fruit weights were obtained with halosulfuron at 36 g/ha rate of halosulfuron, although these weights were not significantly different from the weed-free check or the 18 g/ha and 54 g/ha application rates. In contrast, fruit weight in the weedy check was about half of the lowest fruit weights of any of the halosulfuron treatments at 5 WAE.

Halosulfuron POST stunted watermelon when applied 1 to 3 WAE (Table 3). These timings also corresponded with those that gave greatest weed control, in particular for eclipta and, to a lesser extent, for pigweed species. For cutleaf groundcherry, the two earliest applications were needed to achieve the greatest control and only the 1-WAE application provided a degree of control that would be considered "acceptable" (80 to 90%). On the basis of our experience, cutleaf groundcherry is a weed that can be difficult to control in vegetables. Pigweed is readily controlled with PRE application of halosulfuron in direct-seeded watermelon (Brandenberger et al. 2005a). Some pigweed species are listed as being controlled by POST applications of halosulfuron in agronomic crops. However, the product registration states that applications should be made when pigweed is no taller than 7.5 cm for a 35 g/ha application rate. In addition, the maximum registered use rate for halosulfuron products in some agronomic crops is greater than rates used in vegetables. We typically observe that the pigweed species that were evaluated in these studies, Palmer amaranth and tumble pigweed, often emerge along with watermelon and grow to beyond 7 cm in height within 2 to 3 wk. These rate differences and weed size considerations help explain the lack of pigweed control by the applications made later than 1 WAE. For eclipta, acceptable weed control was obtained with the 5-WAE treatment. Eclipta tends to emerge later than pigweed species and cutleaf groundcherry at the Lane site. Wehtje et al. (2006) found that eclipta was controlled by foliar and root uptake of halosulfuron in container culture. Consequently, some of the control received from the earlier POST applications may have been a result of eclipta control before it emerged. However, on the basis of field observations in the current study, the herbicide was also effective when applied POST to eclipta that had already emerged.

In summary, the detrimental effects of halosulfuron on watermelon were short-lived in this study. The beneficial effects of halosulfuron on weed control outweighed the negative effects that resulted from POST application of halosulfuron. Watermelon stunting was greatest (24%) after the 1-WAE treatment. However, fruit yields for this treatment were essentially identical to those of the weed-free treatment. Thus, the primary impact of this treatment was the weed control it provided. Although part of the weed control observed in this study was due to the PRE application of ethalfluralin, the effect of halosulfuron was substantial. For example, ethalfluralin PRE at double the rate used in the present study provided less than 50% control of cutleaf groundcherry (Brandenberger et al. 2005a). Ethalfluralin also provided partial, but not complete, control of pigweed and eclipta in the present study. The crop safety we observed with halosulfuron is of particular interest. Webster and Culpepper

Table 4. Effect of halosulfuron application rates and timings on watermelon yield across locations (Bixby and Lane) and years.[a,b]

Treatment	Application		Yield[c]	
	Rate	Timing		
	g/ha	WAE	Mg/ha	Fruits/ha
Halosulfuron	18	5	24.8 cd	3,790 ab
Halosulfuron	27	5	22.5 d	3,480 b
Halosulfuron	36	5	30.3 abc	4,310 ab
Halosulfuron	54	5	25.3 bcd	3,590 ab
Halosulfuron	27	1	30.8 abc	4,990 a
Halosulfuron	27	2	27.5 abcd	4,380 ab
Halosulfuron	27	3	32.9 a	4,660 a
Halosulfuron	27	7	25.6 bcd	3,700 ab
Weedy check	-	-	12.2 e	1,870 c
Weed-free check	-	-	31.1 abc	4,340 ab

[a] Halosulfuron treatments included a nonionic surfactant at 0.25% v/v and were preceded by a PRE application of ethalfluralin @ 840 g/ha.

[b] Abbreviation: WAE, weeks after emergence of watermelon.

[c] Values within a column followed by the same letter are not significantly different (P = 0.05).

(2005) found that halosulfuron applied PRE reduced squash plant growth and early fruit production but not total-season production. Because we used a single harvest, it is not possible to ascertain whether earliness of watermelon fruit maturity was affected by POST application of halosulfuron.

The horticultural importance of halosulfuron as a PRE herbicide to control common weeds in direct-seeded watermelon production was previously demonstrated (Brandenberger et al. 2005a). However, growers sometimes need additional options. Our studies show that another acceptable use for halosulfuron in watermelon production would be a POST application. For watermelon growers who frequently rotate crops to avoid disease problems, and do not always know what weeds to expect at the time of planting, a POST application option would offer an opportunity to respond to the emerging weed species spectrum on an as-needed basis. This option would contribute to more judicious herbicide use and possible reduction in production costs.

Sources of Materials

[1] Monosem model NG Plus, ATI, Inc. 17135 West 116th St., Lenexa, KS 66219.

[2] Planet Jr., Powell Manufacturing Company, P.O. Box 707, Bennettsville, SC 29512-0707.

[3] DGTeeJet 11004, DGTeeJet 11003, TeeJet 8002 VS spray nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.

[4] Surf-Ac, nonionic biodegradable surfactant, Drexel Chemical Company, P.O. Box 13327, Memphis, TN 38113-0327 or SurfKing nonionic surfactant blend, Estes, Inc., P.O. Box 8287, Wichita Falls, TX 76307.

[5] SAS Institute, Inc., 100 SAS Campus Dr., Cary, NC 27513.

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